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23. Ultrahigh Strength (1500 MPa class) Steel

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Contents:

Key Words: *Ausoformed (AF) martensitic steel, Hydrogen embrittlement (HE), Critical diffusible hydrogen content (H_c), Fatigue strength under 10^8 cycles*

1. Summary

A research program on ultrahigh strength (1500 MPa class) steel with high resistance to hydrogen embrittlement (HE) and fatigue damage is ongoing under the *Ultra Steel* project at the National Intstitute for Materials Science (NIMS), funded by the Ministry of Education, Science and Technology. For more information on the Ultra Steel Project:
http://www.ehis.navy.mil/tp/asia/kameda/Ultrasteel.doc

Ausformed Martensitic Steel

For the purpose of improving the resistance of ultrahigh strength martensitic steel to HE and fatigue, unique martinensitic microstructure of SCM440 (0.42%C-0.2%Si-0.83%Mn- 1.08%Cr-0.16%Mo) steels, which are different from conventional QT steels, are tailored using an ausforming process. The SCM440 steel is equivalent to 4140 type steel. Ausformed (AF) steel was produced through thermomechanical processing consisting of three stages: (i) austenitization at 1323 or 1153 K, (ii) hot rolling by 30-80% at 1243-1023 K followed by water-quenching and (iii) tempering by induction or furnace heating systems. The AF steel had serrated prior austenite grain boundaries unlike smooth boundaries in the QT steel. Low temperature AF steels exhibited uniform distribution of fine carbides in both the grain matrix and boundaries. Intergranular (IG) film-like carbides formed in high temperature AF steel. Tempering by induction heating produced finer microstructure than that by furnace heating due to suppressing the precipitate coarsening during rapid cooling. The prior austenite grain size and tensile strength (σ_B) can be controlled by the austenitizing or ausforming and tempering temperatures, respectively. Bar (12 mm ϕ and 1 m long) and plates (12 mm thick, 100 mm wide and 500 mm long) of AF steel have been fabricated.

Susceptibility to Hydrogen Embrittlement (HE)

HE tests on the AF and QT steels were performed using notched round bar specimens. Specimens, which had been cathodically charged with hydrogen followed by Cd plating, were loaded under 90% of the σ_B. The susceptibility of ultrahigh strength steels to HE is evaluated in terms of the critical diffusible hydrogen content (H_c) in specimens to which the threshold stress for hydrogen-induced cracking is applied. The diffusible hydrogen, which is released from weak trapping sites when heated to 573 K, was determined by thermal desorption analysis. Higher values of H_c represent high resistance to HE. As shown in Fig. 1, IG cracking, observed in the QT steel with high susceptibility to HE, requires much lower H_c than transgranular (TG) cracking in the AF steel. Although AF steels with $\sigma_B < 1600$ MPa showed superior resistance to HE than QT steels with similar σ_B, the H_c asymptotically decreased with increasing σ_B and the difference in H_c between the AF and QT steel became minimal when $\sigma_B > 1800$ MPa (Fig. 2). During emersion tests using a 0.1mol HCl solution, the AF steel absorbed much smaller amounts of hydrogen than the QT steel, both of which showed similar HE susceptibility under the σ_B of 1900-1950 MPa. This means that the equilibrium hydrogen content is not related to the HE susceptibility. Moreover, decreasing the grain size from 17 to 3 μm in AF steel with the σ_B of 1400 MPa led to a two-fold increase in H_c.

Fatigue Behavior under 10^8 Cycles

In ultrahigh strength QT steels subjected to high cycle fatigue, cracks predominantly initiate from hard/stiff inclusions such as TiN and Al_2O_3 but not from soft ones like MnS and SiO_2, which are located inside specimens. The internal initiation of fatigue cracks, which prevents extending the fatigue life of the ultrahigh strength steel, is related to HE at the inclusions. Thus, the AF steel with high HE resistance is expected to improve the fatigue strength (σ_w) under10^8 cycles performed using an electro-magnetic resonant machine. AF steels (SCM440) with prior austenite grain size of 18 μm showed σ_w of 930 MPa (σ_w/σ_B =0.62), which is far better than QT steels with σ_w of 650 MPa (σ_w/σ_B =0.55). Fatigue cracks of the AF steel initiated from the surface due to the elimination of HE at internal hard inclusion sites. Similar behavior was observed in spring steel (SUP12).

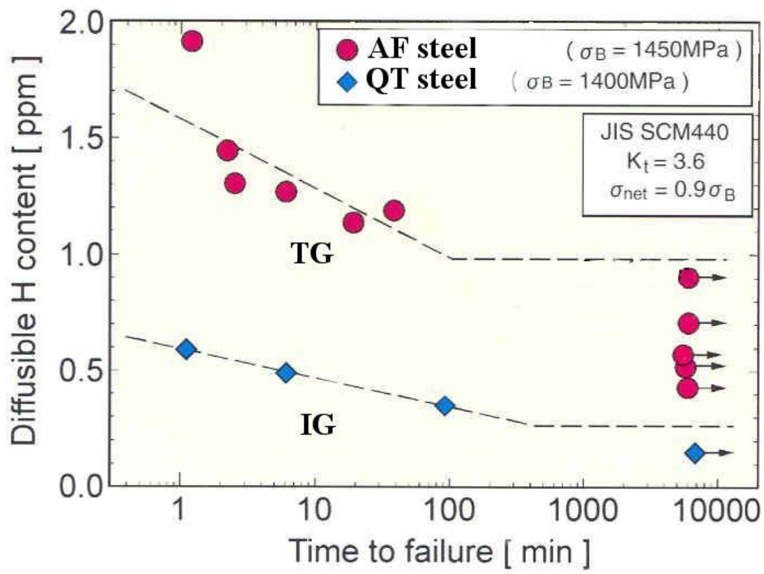

Figure 1. Dependence of diffusible hydrogen content on failure time for intergranular (IG) and transgranular (TG) cracking observed, respectively, in QT and AF steels

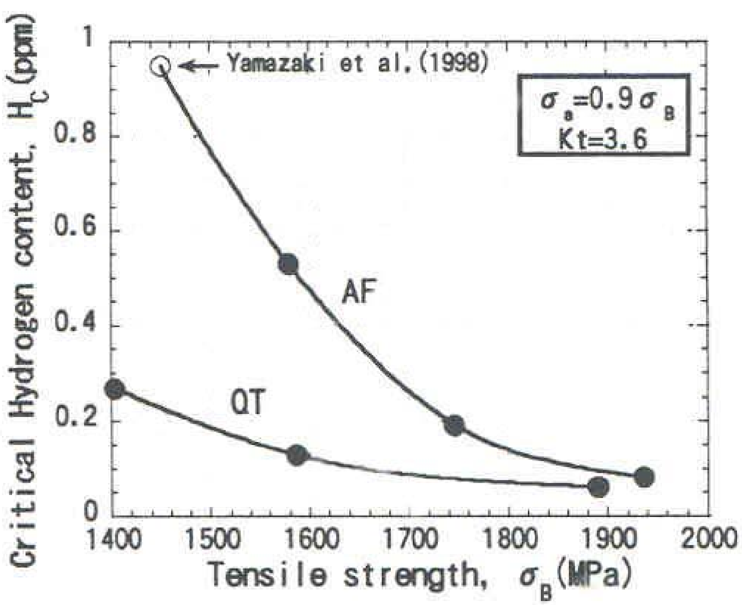

Figure 2. Variation of critical diffusible hydrogen with tensile strength in AF and QT steels.

2. Background

The ultimate goal of this project is to design advanced ultrahigh strength steels, which have high resistance to HE and improved fatigue strength under high cycles. Some other programs under the Ultra Steel project at the NIMS are reported at the below sites:

Marine Corrosion Resistant Steel: http://www.ehis.navy.mil/tp/asia/kameda/marinecorr.doc
Weldable 800MPa Class Steel: http://www.ehis.navy.mil/tp/asia/kameda/weldablesteel.doc
Heat Resistant Steel: http://www.ehis.navy.mil/tp/asia/kameda/ultracreep.doc
http://www.ehis.navy.mil/tp/asia/kameda/creepfoldyna.doc

3. Assessment

Development of AF ultrahigh strength steels less susceptible to HE and fatigue damage is a critical materials issue to naval aircraft. ONR currently funds ongoing AF processing programs.

4. Points of Contact

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